The Pronator Quadratus and Distal Anterior Interosseous Nerve: A Cadaveric Study

Richard M. Hinds, MD[1] Michael B. Gottschalk, MD[1] John T. Capo, MD[1]

[1] Division of Hand Surgery, New York University Hospital for Joint Diseases, New York, New York

Address for correspondence Richard M. Hinds, MD, Division of Hand Surgery, New York University Hospital for Joint Diseases, 301 East 17th Street, New York, NY 10003 (e-mail: RichardHindsResearch@gmail.com).

J Wrist Surg 2015;4:183–187.

Abstract

Background The pronator quadratus (PQ) muscle is an important and commonly encountered structure in surgery of the wrist. A thorough understanding of the anatomy of the PQ and the anterior interosseous nerve (AIN), which innervates the PQ, is important, particularly during distal radius fracture osteosynthesis and distal AIN transfer to deep branch of the ulnar nerve. Furthermore, there is a paucity of literature regarding sex differences in the morphology of these structures. We describe the morphology of the PQ and AIN and compare PQ and AIN findings in male and female specimens.

Methods Twenty-five cadaveric upper extremities underwent loupe-aided dissection of the volar forearm with identification of the AIN and PQ. A digital photograph taken perpendicular to the volar surface of the forearm was used to measure the PQ and assess AIN morphology using ImageJ (National Institutes of Health; Bethesda, MD). Comparisons between male and female specimens were performed.

Results Of the 25 specimens, 84% appeared as a single trapezoidal muscle bundle, with the remaining 16% demonstrating a double-bundle morphology. The PQ was a mean 3.8 ± 0.5 cm in radial-ulnar width and 4.6 ± 0.7 cm in proximal-distal length with a mean thickness, area, and volume of 0.6 ± 0.2 cm, 18.2 ± 4.8 cm^2, and 10.5 ± 3.7 cm^3, respectively. The PQ branch of the AIN was a mean 3.8 ± 1.1 cm long and had a mean diameter of 1.4 ± 0.2 mm. Male specimens demonstrated significantly greater radial-ulnar width ($p = 0.005$), area ($p = 0.006$), and volume ($p = 0.033$) of the PQ, as well as a greater distance from the radial styloid to the distal arborization of the AIN ($p = 0.005$) compared with female specimens.

Conclusions The current study informs hand surgeons of the morphologic variability and sexual dimorphism of the PQ and AIN and may help guide operative planning.

Keywords
- anterior interosseous nerve
- distal radius
- fracture
- nerve transfer
- pronator quadratus

The pronator quadratus (PQ) muscle is an important and commonly encountered structure in surgery of the wrist. The muscle is often trapezoidal in shape and is composed of two distinct heads: the superficial head and the deep head.[1–3] The superficial head has been reported to be the predominant muscle functioning in pronation, with the deep head serving as a dynamic stabilizer of the distal radioulnar joint (DRUJ).[4] The PQ is innervated by the anterior interosseous nerve (AIN), a branch of the median nerve also supplying motor innervation to the flexor digitorum profundus (FDP) and flexor pollicis longus (FPL) muscles.

A thorough understanding of PQ and AIN anatomy is important, particularly during distal radius fracture osteosynthesis and distal AIN transfer to deep branch of the ulnar nerve. Furthermore, there is a paucity of literature regarding sex differences in the morphology of these structures. The

Copyright © 2015 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA.
Tel: +1(212) 584-4662.

DOI http://dx.doi.org/10.1055/s-0035-1556858.
ISSN 2163-3916.

This document was downloaded for personal use only. Unauthorized distribution is strictly prohibited.

Fig. 1 Photograph of the volar forearm displaying the area within the dashed line approximating the area of the pronator quadratus as measured with ImageJ. Note also that in this specimen the green pin indicates the radial styloid, the red pin indicates the volar lip of the scaphoid facet, the blue pin indicates the volar lip of the lunate facet, the black pin indicates the ulnar styloid, and the orange pin indicates the location of the AIN as it passes the proximal border of the PQ.

Fig. 2 Photograph of the volar forearm demonstrating an example of a PQ with a single-muscle-bundle morphology.

purpose of this investigation was twofold: (1) to describe the PQ dimensions and proximity to important anatomic landmarks as well as to report the course of the AIN as it innervates the PQ, and (2) to compare PQ and AIN findings in male and female cadaveric specimens. We believe such an anatomic study will be helpful in guiding PQ incision and reflection for surgical exposure in distal radius fracture fixation as well as in harvesting the AIN for ulnar nerve motor branch transfer procedures. Hand surgeons may also find our quantitative analysis of the sexual dimorphism of these structures to be helpful for operative planning.

Materials and Methods

Twenty-five preserved left upper extremities from donated cadaveric specimens were examined in this investigation. Mean age of the donors at the time of death was 81 years (range, 48 to 100). Fourteen donors were male and eleven were female. The specimens were disarticulated at the elbow and underwent loupe-aided dissection of the volar forearm with identification of the AIN and PQ. A digital photograph taken 15 cm above and perpendicular to the volar surface of the forearm was used to perform measurement of the PQ using the advanced imaging program ImageJ (National Institutes of Health; Bethesda, MD). ImageJ has been utilized in multiple orthopaedic investigations to quantify area via image capture.[5–7] It uses a known distance captured in the image (such as a ruler), which allows for calibrated assessment of distance and area by measuring the number of pixels outlined in the image as the region of interest (►**Fig. 1**).[7] Anatomic points of interest were marked with pins under direct visualization and included the radial styloid, ulnar styloid, and volar lip of the scaphoid and lunate fossa of the radius. Additionally, the AIN and branch points as well as the proximal and distal articular portions of the ulnar head were explored. The thickness (measured on a slice taken from the center of the PQ) and the proximal-distal and radial-ulnar dimensions of the PQ were also assessed. Volume was calculated by multiplying the area by the thickness. Comparisons between male and female specimens were performed using Wilcoxon/Kruskal-Wallis tests and Pearson χ^2 tests to analyze continuous and categorical data, respectively. The level of significance for all tests was $p < 0.05$.

Results

The PQ appeared as a single trapezoidal muscle bundle, with its tendinous origin located along the volar surface of the ulna, in 84% (21 of 25) of the specimens (►**Fig. 2**). The remaining 16% (4 of 25) demonstrated a double-muscle-bundle morphology, with the distal bundle's tendinous origin located on the volar surface of the ulna and the proximal bundle's tendinous portion originating from the volar radius (►**Fig. 3**). The PQ was a mean 3.8 ± 0.5 cm in radial-ulnar width and 4.6 ± 0.7 cm in proximal-distal length. Mean PQ thickness, area, and volume were 0.6 ± 0.2 cm, 18.2 ± 4.8 cm^2, and 10.5 ± 3.7 cm^3, respectively. The distal border of the PQ was a mean 1.2 cm $\pm$ 0.2 from the radial styloid, 0.8 ± 0.2 cm from the scaphoid facet, 1.1 ± 0.4 cm from the lunate facet, and 1.2 ± 0.3 cm from the ulnar styloid. The radial aspect of the distal border of the PQ was directly adjacent to the origin of the volar radiocarpal capsule. The proximal and distal borders of

Fig. 3 Photograph of the volar forearm demonstrating an example of a PQ with a double-muscle-bundle morphology.

This document was downloaded for personal use only. Unauthorized distribution is strictly prohibited.

Table 1 PQ data summary

Measurement	Units	Total ($n = 25$)	Males ($n = 14$)	Females ($n = 11$)	p Value
Radial-ulnar length (SD)	cm	3.8 (0.5)	4.0 (0.3)	3.6 (0.5)	0.005
Proximal-distal length (SD)	cm	4.6 (0.7)	4.8 (0.8)	4.4 (0.4)	0.250
Thickness (SD)	cm	0.6 (0.2)	0.6 (0.2)	0.6 (0.1)	0.720
Area (SD)	cm^2	18.2 (4.8)	20.4 (5.1)	15.3 (2.3)	0.006
Volume (SD)	cm^3	10.5 (3.7)	11.8 (4.0)	8.7 (2.5)	0.033
RS to PQ (SD)	cm	1.2 (0.2)	1.2 (0.4)	1.1 (0.2)	0.380
SF to PQ (SD)	cm	0.8 (0.2)	0.8 (0.2)	0.8 (0.2)	0.700
LF to PQ (SD)	cm	1.1 (0.4)	1.1 (0.1)	1.1 (0.9)	0.260
US to PQ (SD)	cm	1.2 (0.3)	1.2 (0.4)	1.1 (0.2)	0.320
PU to PQ (SD)	cm	0.2 (0.1)	0.3 (0.1)	0.2 (0.1)	0.337
DU to PQ (SD)	cm	0.7 (0.2)	0.7 (0.2)	0.7 (0.3)	0.956
Double bundle PQ (%)	N/A	4 (16)	2 (14)	2 (18)	0.792

Abbreviations: DU, distal articular surface of ulnar head; LF, lunate facet; PQ, pronator quadratus; PU, proximal articular surface of ulnar head; RS, radial styloid; SD, standard deviation; SF, scaphoid facet; US, ulnar styloid.

the articular surface of the ulnar head were a mean 0.2 ± 0.1 cm and 0.7 ± 0.2 cm from the ulnar aspect of the distal PQ border, respectively. Male specimens also demonstrated significantly greater radial-ulnar width (4.0 cm vs 3.6 cm; $p = 0.005$), area (20.4 cm^2 vs 15.3 cm^2; $p = 0.006$), and volume (11.8 cm^3 vs 8.7 cm^3; $p = 0.033$) of the PQ compared with female specimens. There was no statistically significant difference in PQ bundle morphology between male and female specimens. PQ data are summarized in ►**Table 1**.

After giving off distal branches innervating the FDP and FPL, the AIN traveled a mean distance of 2.2 ± 0.9 cm before reaching the proximal border of the PQ. Along with a branch from the anterior interosseous artery, the AIN first courses between the deep surface of the PQ and the interosseous membrane. It then branches at a mean 1.7 ± 0.8 cm distal to the proximal PQ border before penetrating the deep surface of the PQ. This in total confers a mean AIN distance of 3.8 ± 1.1 cm from the distalmost FDP/FPL branches to the distal arborization at the level of the PQ. The mean diameter of the AIN as it passed the proximal border of the PQ was 1.4 ± 0.2 mm. The distal branch point of the AIN on the PQ was found a mean 5.5 ± 0.6 cm from the radial styloid, 4.8 ± 0.6 cm from the scaphoid facet, 4.2 ± 0.6 cm from the lunate facet, and 4.2 ± 0.5 cm from the ulnar styloid. The distance from the radial styloid to the distal arborization of the AIN was significantly greater in male specimens than in female specimens (5.8 vs 5.2 cm; $p = 0.005$). AIN data are summarized in ►**Table 2**.

Discussion

The purpose of this study was to describe the morphology and anatomic features of the PQ and AIN as well as to compare findings in male and female specimens. In our

Table 2 AIN data summary

Measurement (cm)	Total ($n = 25$)	Males ($n = 14$)	Females ($n = 11$)	p Value
AIN proximal branch to PQ (SD)	2.2 (0.9)	2.3 (0.8)	2.0 (0.9)	0.311
PQ to AIN distal branch (SD)	1.7 (0.8)	1.8 (1.0)	1.5 (0.4)	0.600
AIN proximal-distal length (SD)	3.8 (1.1)	4.1 (1.1)	3.5 (1.0)	0.198
AIN diameter (SD)	0.1 (0.0)	0.1 (0.0)	0.1 (0.0)	0.955
RS to AIN distal branch (SD)	5.5 (0.6)	5.8 (0.5)	5.2 (0.5)	0.005
SF to AIN distal branch (SD)	4.8 (0.6)	5.0 (0.6)	4.6 (0.5)	0.100
LF to AIN distal branch (SD)	4.2 (0.6)	4.4 (0.7)	4.0 (0.5)	0.147
US to AIN distal branch (SD)	4.2 (0.5)	4.4 (0.6)	4.0 (0.4)	0.139

Abbreviations: AIN, anterior interosseous nerve; LF, lunate facet; PQ, pronator quadratus; RS, radial styloid; SD, standard deviation; SF, scaphoid facet; US, ulnar styloid.

This document was downloaded for personal use only. Unauthorized distribution is strictly prohibited.

study, 84% of the specimens consisted of a single muscle bundle originating from the volar surface of the ulna, with the remaining 16% demonstrating a double-bundle morphology. Our findings are supported by previously published studies. Stuart performed dissection and assessment of 40 cadaveric forearms and found that 20% of his specimens had a PQ with a double-muscle-bundle morphology.[4] To the contrary, Sakamoto et al found a multiple-muscle-bundle morphology of the PQ in 32 of the 40 forearms examined in their study.[2] Furthermore, Johnson and Shrewsbury as well as Macalister have described the variable morphology of the PQ, though neither reported the incidence of single-trapezoidal-bundle or double-bundle PQ morphologies in their respective studies.[1,8]

Few prior investigations have evaluated the anatomic dimensions of the PQ as a whole and its relationship to the volar wrist. In a clinical study by Lo and Cheng, the PQ was measured at the time of open reduction and internal fixation for the treatment of 52 distal radius fractures.[9] The authors reported an average proximal-distal PQ length of 3.72 cm, scaphoid fossa–distal PQ edge distance of 1.76 cm, and lunate fossa–distal PQ edge distance of 1.62 cm. However, interpretation of findings reported in that study may be limited by anatomic distortion secondary to the distal radius fracture. Takada et al performed a cadaveric study and found an average proximal-distal PQ length of 3.54 cm and an average distance from the distal PQ edge to the radiocarpal joint of 1.66 cm among 10 cadaveric forearms.[10] In our study, the PQ was a mean 3.8 cm in radial-ulnar length and 4.6 cm in proximal-distal length, with the distal border of the PQ a mean distance of 0.8 cm from the scaphoid facet and 1.1 cm from the lunate facet. The etiology of the discrepancy in measured values between our study and the former investigations is likely multifactorial. Our study utilized a validated advanced imaging program to perform digital measurements of the PQ instead of calipers used in the other studies. Additionally, variation in the size of the PQ and other anatomic structures may be dependent on the population from which the patients were recruited or cadaveric specimens donated.

The location of the distal border of the PQ has important anatomic implications. In our study, the radial aspect of the distal PQ border was directly adjacent to the origin of the volar radiocarpal capsule, while the ulnar aspect was found to overlay the proximal third of the ulnar head. Damage to the capsule may lead to instability and pain, as volar capsuloligamentous structures have been shown to be integral to radiocarpal stability.[11,12] As such, we recommend incising the distal PQ at the immediate distal edge, just slightly within the muscle substance, to avoid capsuloligamentous damage while obtaining exposure for fixation of distal radius fractures.

In the current study, we found a mean AIN diameter of 1.4 mm as it traversed the proximal border of the PQ and a mean length of 3.8 cm from the distalmost FDP/FPL branches to the distal AIN arborization. AIN diameter presented in the literature is comparable to our findings, with reported values ranging from 0.8 to 2 mm.[13–15] Regarding length, we believe an AIN length of 3.8 cm is feasible for utilization for ulnar nerve motor branch transfers based upon findings by Ustün et al.[16] The authors of that cadaveric study reported an average distance of 1 cm between the AIN motor branch to the PQ and the motor branch of the ulnar nerve at the level of the dorsal sensory branch. Furthermore, they conclude that the AIN motor branch to the PQ is the distalmost level of the AIN suitable for distal AIN transfer to motor branch of the ulnar nerve and is in close proximity to the ulnar nerve motor endpoints.

Our results also indicate sexual dimorphism of the PQ and AIN. Male specimens had significantly greater radial-ulnar width ($p = 0.005$), area ($p = 0.006$), and volume ($p = 0.033$) of the PQ, as well as a greater distance from the radial styloid to the distal arborization of the AIN ($p = 0.005$), compared with female specimens. Sex differences in the morphology of the PQ have also been reported in the literature. Sato et al found a significantly thicker PQ in men as compared with women in their study examining the sonographic appearance of the PQ in 30 healthy volunteers.[17] These findings suggest that PQ reconstruction after distal radius fracture fixation may portend a greater challenge in female patients because of their generally smaller PQ. This has particular impact because women account for the largest proportion of distal radius fracture surgical patients.[18]

There are limitations to the current study. First, as with any cadaveric investigation, tissue characteristics in our study likely vary from those seen intraoperatively. Next, use of advanced imaging software for two-dimensional quantitative analysis of three-dimensional structures may only approximate dimensions. However, image distortion was mitigated by taking the digital images directly above and perpendicular to the volar forearm exposure. Finally, unilateral dissection and analysis of the specimens in our study may reduce the generalizability of our findings. However, our study serves to improve understanding of the PQ, distal AIN, and sexual dimorphism related to these structures.

In conclusion, our study has reported the dimensions of the PQ and its proximity to important anatomic landmarks of the wrist. We have found the PQ to be a morphologically variable muscle featuring either a single-muscle-bundle or a double-bundle-morphology. Our findings may serve as helpful references for obtaining surgical exposure through the PQ during operative fixation of distal radius fractures as well as in ulnar nerve motor branch transfer procedures using the distal AIN. Our study also quantitatively demonstrates the sexual dimorphism of the PQ and AIN.

Conflict of Interest
None

Statement of Human and Animal Rights
All procedures followed as part of this study were in accordance with ethical standards of the Institutional

This document was downloaded for personal use only. Unauthorized distribution is strictly prohibited.

Review Board and with the Helsinki Declaration of 1975, revised in 2000.

Statement of Informed Consent

Informed consent was not obtained, as this was a cadaveric study. ►**Figs. 1**, **2**, and **3** include images of cadaveric specimens; however, no identifiable features are present, and confidentiality is maintained.

Acknowledgments

The authors would like to thank George Lew for his assistance in the cadaveric laboratory.

References

1 Johnson RK, Shrewsbury MM. The pronator quadratus in motions and in stabilization of the radius and ulna at the distal radioulnar joint. J Hand Surg Am 1976;1(3):205–209
2 Sakamoto K, Nasu H, Nimura A, Hamada J, Akita K. An anatomic study of the structure and innervation of the pronator quadratus muscle. Anat Sci Int 2015;90(2):82–88
3 Svízenská I, Cizmár I, Visna P. An anatomical study of the anterior interosseous nerve and its innervation of the pronator quadratus muscle. J Hand Surg [Br] 2005;30(6):635–637
4 Stuart PR. Pronator quadratus revisited. J Hand Surg [Br] 1996; 21(6):714–722
5 Beltran MJ, Blair JA, Huh J, Kirby JM, Hsu JR; Skeletal Trauma Research Consortium (STReC). Articular exposure with the Swashbuckler versus a "Mini-swashbuckler" approach. Injury 2013; 44(2):189–193
6 Grogan BF, Blair JA, Blease RE, Cho MS, Hsu JR. Exposure of the distal humerus using a triceps hemi-peel approach. Orthopedics 2014;37(5):e455–e459
7 Salassa TE, Hill BW, Cole PA. Quantitative comparison of exposure for the posterior Judet approach to the scapula with and without deltoid takedown. J Shoulder Elbow Surg 2014;23(11):1747–1752
8 Macalister A. The varieties of the pronator quadratus. J Anat Physiol 1870;5(Pt 1):32–34
9 Lo HY, Cheng HY. Clinical study of the pronator quadratus muscle: anatomical features and feasibility of pronator-sparing surgery. BMC Musculoskelet Disord 2014;15:136
10 Takada N, Otsuka T. Anatomical features of the pronator quadratus muscle related to minimally invasive plate osteosynthesis of distal radial fractures with a volar locking plate: a cadaver study. Eur Orthop Traumatol. 2011;2:133–136
11 Brown D, Mulligan MT, Uhl RL. Volar ligament repair for radiocarpal fracture-dislocation. Orthopedics 2013;36(6):463–468
12 Katz DA, Green JK, Werner FW, Loftus JB. Capsuloligamentous restraints to dorsal and palmar carpal translation. J Hand Surg Am 2003;28(4):610–613
13 Berger RA. Partial denervation of the wrist: a new approach. Tech Hand Up Extrem Surg 1998;2(1):25–35
14 Grafe MW, Kim PD, Rosenwasser MP, Strauch RJ. Wrist denervation and the anterior interosseous nerve: anatomic considerations. J Hand Surg Am 2005;30(6):1221–1225
15 Schenck TL, Stewart J, Lin S, Aichler M, Machens HG, Giunta RE. Anatomical and histomorphometric observations on the transfer of the anterior interosseous nerve to the deep branch of the ulnar nerve. J Hand Surg Eur Vol 2014
16 Ustün ME, Oğün TC, Büyükmumcu M, Salbacak A. Selective restoration of motor function in the ulnar nerve by transfer of the anterior interosseous nerve. An anatomical feasibility study. J Bone Joint Surg Am 2001;83-A(4):549–552
17 Sato J, Ishii Y, Noguchi H, Takeda M, Toyabe S. Sonographic appearance of the pronator quadratus muscle in healthy volunteers. J Ultrasound Med 2014;33(1):111–117
18 Mellstrand-Navarro C, Pettersson HJ, Tornqvist H, Ponzer S. The operative treatment of fractures of the distal radius is increasing: results from a nationwide Swedish study. Bone Joint J 2014;96-B(7):963–969

This document was downloaded for personal use only. Unauthorized distribution is strictly prohibited.